

A 20-YEAR INDUSTRY PLAN FOR BUILDING ENVELOPES

# BUILDING ENVELOPE

## TECHNOLOGY ROADMAP

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Facilitated by:

OFFICE OF BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS

ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

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This roadmap was developed by diverse representatives of the building envelope industry, including builders, building product manufacturers, industry associations, specialized design professionals, academics, researchers, code bodies, distributors, and contracting firms.

The complete *Building Envelope Technology Roadmap* is available on the Internet at [http://www.eren.doe.gov/buildings/technology\\_roadmaps/envelope](http://www.eren.doe.gov/buildings/technology_roadmaps/envelope)

The importance of integrating building envelopes with other components and systems in order to maximize benefits must not be overlooked. This *Building Envelope Technology Roadmap* is one of a suite of related roadmaps, including:

- *Vision 2020: The Lighting Technology Roadmap*
- *High-Performance Commercial Buildings: A Technology Roadmap*
- *Window Industry Technology Roadmap*
- *HVAC&R Research for the 21st Century* (with the Air-Conditioning and Refrigeration Technology Institute)
- With the Partnership for Advancing Technology in Housing:
  - Information Technology to Accelerate and Streamline Home Building
  - Advanced Panelized-Type Systems
  - Whole House and Building Process Redesign
  - Existing Home Technologies
  - Manufactured Housing

## Pushing the Envelope for Residential Buildings

**The residential building envelope industry includes builders, building product manufacturers, industry organizations, specialized design professionals, academics, researchers, code bodies, distributors, and contracting firms that contribute to the foundations, walls, and roofs of buildings.** As a subset of the residential construction industry, the building envelope industry has been highly successful in the past decade, one of the longest periods of expansion in the past 50 years.<sup>1</sup> Looking ahead, strong demand for housing and remodeling is expected to continue.

As we enter the new millennium, new trends, both social and technological, are affecting the building envelope industry. In a market driven by increased competition, how can the industry develop a building envelope that meets the demands of the consumer (lower cost, more adaptable, smarter, lower maintenance) while reducing the impact on the environment (energy, air, water, and waste)?

This *Building Envelope Technology Roadmap* represents a year of collaboration by more than 100 leaders in the building envelope industry who were asked to envision the envelope of the future and the process for creating it. Its goal is to serve as a tool for further collaboration and a platform for communication by which public and private research, development, and deployment (RD&D) agendas can be aligned.

### A NEW INITIATIVE

The U.S. Department of Energy's Office of Building Technology, State and Community Programs (BTS) is facilitating a new industry-led initiative to develop a series of technology roadmaps. The roadmaps identify shared visions, key goals, and strategies for different areas of the building and equipment industries.

The roadmapping initiative is a fundamental component of the BTS strategic plan and will help to align government resources with the industry's high-priority needs. This roadmap will guide cooperation among public and private researchers, building envelope industry members, and other State and Federal offices to help achieve the 2020 vision for the building envelope industry.

<sup>1</sup> "State of the Nation's Housing," Joint Center for Housing Studies, Harvard University, 2000.

In the vision for 2020, key market and policy barriers have been overcome and technological innovations allow the building envelope to become a net producer of energy, provide adjustable space through walls that move, and adaptable rooms that change as needs and environmental factors change. Intelligent features will allow the building to adjust the inside climate based on the outside weather, provide naturally derived lighting and ventilation, and have light and heat

follow a person through the home. Increased durability will free up time and money spent on maintenance. The overall amount of material, time in construction, energy consumption, and expense of the exterior wall system will be minimized.

***In 2020, building envelopes will be energy-positive, adaptable, affordable, environmental, healthy, intelligent, and durable.***

## VISION

In 2020, building envelopes will be—

**Energy-positive**—minimizing energy use; providing heating, cooling, and electricity; and storing or returning excess electricity to the grid.

**Adaptable**—designed for movable walls, convertible rooms, and flexible systems to accommodate the changing needs of occupants (e.g., newborns to seniors) and future technological innovations.

**Affordable**—cost-effective in terms of comprehensive home ownership, spanning first cost, maintenance cost, life-cycle cost, and resale value.

**Durable**—offering enhanced safety and resistance to natural hazards, including moisture, fire, and disaster, as well as decreased maintenance.

**Environmental**—harmless to the natural environment, resource-efficient, and appropriately balanced between embodied energy and durability.

**Healthy and comfortable**—harmless to the well-being of construction workers and occupants and providing good air quality and flow, thermal and visual comfort, natural ventilation and light, and protection against fire, moisture, chemicals, radon, and noise pollution.

**Intelligent**—using advanced sensors, monitors, controls, and communication technologies to improve resource efficiency, comfort, affordability, adaptability, durability, and environmental harmony.

### Overarching Technology Strategy

Develop, evaluate, and promote the adoption of building envelope materials, systems, and process/design techniques, aligned with one or more of the vision elements.

Materials	Systems	Process/Design	Performance Evaluation
<ul style="list-style-type: none"><li>• Advanced Aggregate Materials</li><li>• Advanced Insulation</li><li>• Air/Vapor Barriers</li><li>• Cellular Building Components</li><li>• Disaster-Resistant Materials</li><li>• Fabric Technology</li><li>• Intelligent Materials</li><li>• Moisture-Control Materials</li><li>• Nontoxic Materials</li><li>• Radiant Technologies</li><li>• Resource-Efficient Materials</li></ul>	<ul style="list-style-type: none"><li>• Advanced Foundations</li><li>• Advanced Panel/Prefabrication</li><li>• Crawl Spaces</li><li>• Double Envelope</li><li>• Energy Services/Supply</li><li>• Envelope Component Integration</li><li>• Intelligent Envelope Systems</li><li>• Rain Screen</li><li>• Roof/Attic Systems</li><li>• Super Walls</li></ul>	<ul style="list-style-type: none"><li>• Advanced Framing</li><li>• Automation</li><li>• Daylight/Passive Solar Design</li><li>• Design for Adaptability</li><li>• Design for Intelligence</li><li>• Design Tools</li><li>• Modular Coordination</li><li>• Natural Ventilation/IAQ</li><li>• Recycling/Reuse Processes</li><li>• Regional Design</li></ul>	<ul style="list-style-type: none"><li>• Modeling/Testing</li><li>• Monitoring/Testing</li><li>• Rating Criteria</li></ul>

The technical research activities identified by industry span many fields of research and segments of the building envelope industry. They are not meant to be a comprehensive listing but should serve as a well-considered grouping of the issues of greatest importance to the envelope industry.

In order to achieve this vision, two parallel strategies are required. The market/policy strategies outlined in this roadmap will enable industry to overcome key barriers that hinder innovation. The technology strategy suggests new directions for materials, products, systems, design processes, and construction practices that are closely aligned with the vision.

#### Market/Policy Strategies:

1. Promote education/outreach along the construction value chain.
2. Build a platform for collaboration in R&D leading to systems approach and improved envelope construction.
3. Expand skilled workforce trained in labor-reducing technology.
4. Develop a building envelope performance rating system.
5. Support the acceptance of emerging technologies by Codes and Standards.

## INTRODUCTION

### WHAT THE BUILDING ENVELOPE DOES

The building shell—that part of the building that serves as an interface between the interior and exterior environments—includes the foundation (vertical wall and horizontal slab), the above-grade wall, and the roof assembly. It plays a critical role in solar gain management, thermal load control, air infiltration and exfiltration, ventilation, moisture management, fenestration support, impact and disaster resistance, noise control, air-quality management, design value, and aesthetic definition.

### PLATFORM FOR SMART TECHNOLOGY

In a market driven by increased competition, how can the industry provide building envelopes that meet the demands of the consumer (lower cost, more adaptable, smarter, lower maintenance) while reducing impacts on the natural environment (energy, air, water, and waste)? These questions are central to this technology roadmap process, spearheaded by representatives from many segments of the building envelope industry.

This roadmap focuses on residential<sup>2</sup> buildings, including new and existing low-rise multifamily dwellings (garden-style apartments) as well as townhouses and single-family detached homes. These structures are often of similar construction type, design, and materials. Manufactured housing<sup>3</sup> is not directly addressed, given its profound structural and operating differences from site building. However, many of the technical activities listed in this roadmap will yield products that can be applied in the manufactured housing market.

### WHY COLLABORATE?

Defining the industry's long-term vision and strategies can help focus both public and private RD&D investments on industry's highest priorities. It can also facilitate more effective partnerships between industry and government, ensuring that Federal programs enhance, but do not duplicate, industry efforts,

and accelerating the transfer of research results. The magnitude of the undertaking is far beyond any one entity; the roadmap helps break into manageable pieces the work to be done to achieve the vision in 2020.

Over the course of a year, the process stimulated constructive, creative thinking and general consensus on the building envelope of the future, the major barriers standing in the way, and the concrete steps needed to realize the vision. Activities included three workshops, numerous smaller work group meetings, and a survey of more than 300 industry members.

The Federal government has participated alongside industry in this process. The quality and quantity of the Nation's residential housing stock impacts almost all citizens in one way or another. Facilitation of roadmap meetings and documentation has been performed by the Department of Energy's Office of Building Technology, State and Community Programs (BTS), which manages the largest buildings RD&D program in the Federal government.

By joining forces to implement this technology roadmap, leaders in industry are laying the groundwork for residential housing that is increasingly adaptable, affordable, durable, energy- and resource-efficient, comfortable, and supportive of health and well-being.

<sup>2</sup> Some light commercial buildings share many residential building envelope characteristics.

<sup>3</sup> The Manufacturing Housing Research Alliance has initiated its own technology roadmap in collaboration with Partnership for Advancing Technology in Housing (PATH).

## STEPS IN THE ROADMAP DEVELOPMENT PROCESS

### EXECUTIVE FORUM

**When and where:** January 26-27, 2000, Arlington, Virginia  
**Who participated:** 40 senior representatives from the building envelope industry  
**Results:** Summarized the context and history of the building envelope industry, identified trends and drivers affecting the marketplace, and developed a draft vision of building envelopes in the year 2020.

### ROADMAP WORKSHOP 1

**When and where:** June 5-6, 2000, Washington, DC  
**Who participated:** 40 senior and technical representatives from the building envelope industry  
**Results:** Refined the draft vision, identified and prioritized barriers to the vision, and defined actions for overcoming key barriers.

### INDUSTRY SURVEY

**When and where:** June through September, 2000; by mail, e-mail, and Internet  
**Who participated:** 56 senior representatives from the building envelope industry  
**Results:** Generated 120 unique technical research activities, grouped into 35 categories and ranked by risk, contribution to the vision, and potential for addressing key barriers.

### INDUSTRY WORKING GROUPS

**When and where:** June through October 2000; averaging biweekly, 45-minute conference calls  
**Who participated:** Four groups of 5 to 10 building envelope industry representatives  
**Results:** Developed draft recommendations to address key barriers.

### ROADMAP WORKSHOP 2

**When and where:** December 12, 2000, Alexandria, Virginia  
**Who participated:** 50 building envelope industry representatives  
**Results:** Reviewed and fine-tuned the draft roadmap, prioritized strategies, and developed time frame and action plan.

## CONNECTING SMART FEATURES

Since the “smart house” concept emerged in the early 1980s, homeowners and builders have been captivated by the ideas of appliances that talk to each other, garage doors that open with cell phones, and lights that follow occupants through the building. However, industry participants noted that smart buildings are no better than dumb buildings unless the intelligence supports other goals.

## TRENDS IN PERSPECTIVE

Fueled by the strong economy of the 1990s, home ownership in the U.S. set a new record at 66.8 percent in 1999.<sup>4</sup> The market for home improvements and repairs has grown 1.8 percent annually over the last 15 years; sales of many building envelope products have increased as much as 40 percent since 1990.

Looking forward, a number of trends are expected to impact the building envelope industry over the next 20 years. Market trends indicate a shift toward mass customization—modular homes, prefabricated building components, and do-it-yourself improvements and repair products have all experienced significant growth in market share over the last decade. The shift toward time-saving standardization and mass customization of building envelope components is likely to continue.

## THE BUSINESS OF BUILDING ENVELOPES

Despite its economic success, it has been difficult for the U.S. construction industry to develop and deploy innovative technologies and processes.

A primary cause is the extreme complexity of the industry. Hundreds of thousands of companies of all sizes design, build, finance, equip, repair, and retrofit residential building envelopes. Collaboration and communication among these companies is often difficult. In addition, first cost, codes, and familiarity

with products and processes have historically driven the industry. This *Building Envelope Technology Roadmap* is an important first step in uniting the industry to overcome some of the factors that hinder innovation.

## A SUSTAINABLE FUTURE

*In 2020, building envelopes will be energy-positive, adaptable, affordable, environmental, healthy and comfortable, intelligent, and durable.*<sup>5</sup>

**Adaptable**—in the 2020 vision, the external envelope design will incorporate the adaptability or flexibility of the home, and the practical “buildability” issues associated with adaptable design will be resolved. The building envelope will allow:

- Rooms that convert easily from one use to another (e.g., bedroom to office)
- Modular components that allow for movable walls
- Features that allow the system to “grow” as the demographics of the inhabitants change (e.g., aging-in-place)
- System components that are easily adaptable for the future use of innovative technology (e.g., the Vizer hand-held concept, a space holder in the wall for the later addition of solar water heaters)

<sup>4</sup> U.S. Census Bureau.

<sup>5</sup> The vision elements of this technology roadmap are similar to those developed in the other roadmaps listed on the inside cover. They are also mirrored and reinforced in PATH’s strategy and mission.

**Affordable**—The vision for 2020 is one where informed consumers base their decisions upon several home ownership costs. The building envelope of 2020 should be affordable in terms of first cost, maintenance cost, life-cycle cost, and resale value.

**Durable**—In 2020, the building envelope will be more durable and resistant to natural hazards, offering occupants increased safety and decreased maintenance. The building envelope will better withstand moisture, fire, and disaster, and be designed with the structural strength appropriate to its geographic location.

**Energy-positive**—In 2020, the building envelope will minimize heating, cooling, and lighting loads through integrated design and meet remaining loads with non-polluting energy sources, returning excess electricity to the grid. This will save money and reduce greenhouse gas emissions.

**Environmental**—In 2020, the building envelope will be resource-efficient, harmless to the outdoor environment, and appropriately balanced between embodied energy and durability.<sup>6</sup>

“Green building” has many different definitions and strategies. However, most go beyond environmental compliance issues to include reduction of resource use (energy, water, waste); passive building services; reclamation and recycling of components and materials; alternative, recycled and/or environmentally benign materials; and integrated design and construction practices.

**Healthy and comfortable**—The influence of the internal built environment on the comfort, productivity, and health of its occupants is an area of increasing focus. In 2020, the building envelope will enhance air quality, air flow, natural ventilation, and lighting; protect against fire, moisture, chemicals, and radon; reduce noise pollution; and provide thermal and visual comfort.

**Intelligent**—In 2020, intelligent features will increase the affordability, adaptability, durability, energy efficiency, environmental harmony, and positive health impacts of the building envelope. Such features will enable the use of resources (light, water, and energy) only when and where they are needed, storing the excess.

## FACTS AND FIGURES

- Approximately one million low-income renters and owners spent at least half of their monthly income on housing in the late 1990s.<sup>7</sup>
- In 1994-1996, the average total annual expenditures for major replacements/maintenance related to the building envelope included \$7.0 billion for roofing and \$1.7 billion for siding.
- The U.S. residential sector consumed 18.79 quadrillion Btu (\$131.1 billion) in 1998. Over half of this energy was used in space heating and cooling, which are directly impacted by the building envelope, followed by appliances, lighting, and water heating.<sup>8</sup>
- Currently, construction and demolition waste accounts for 24% to 28% of waste by volume in U.S. landfills. In addition, construction materials account for 70% (by weight) of total materials consumption in the U.S.
- According to the U.S. EPA, indoor air quality may be 10 times worse than outdoor air quality.<sup>9</sup>

<sup>7</sup> State of the Nation's Housing, Harvard Joint Center for Housing, 2000.

<sup>8</sup> Energy Information Administration, Annual Energy Outlook 2000, December 1999.

<sup>9</sup> Agenda 21 on Sustainable Construction, CIB Report Publication 237, July 1999.

<sup>6</sup> Low embodied energy needs to be considered with other issues—the best product may have high embodied energy, last for centuries, and then have the energy recaptured. Dave Roodvoets, NRCA Consultant (personal communication), December 2000.

## BARRIERS

### Market Barriers

- Lack of building performance measurability: National standard? [20]\*
- Builder is the largest driver rather than consumer (push rather than pull) [19]
- Fragmentation throughout the construction industry value chain; e.g., lack of leadership, lack of industry vehicle [15]
- Resistance to change (small entrepreneurs) [9]
- Product perception based on market image, not performance [4]

### Policy Barriers

- Lack of nationally accepted building rating system [21]
- Code acceptance, limitations, inconsistencies in costs [17]
- Lack of insurance industry support and involvement [15]
- Code enforcement; lack of inspection [5]
- Tax policy—R&D, incentives [4]
- Codes need to be based on systems as well as on occupational safety and health [4]

### Technology Barriers

- Systems integration of building components and how they function [12]
- Lack of skilled labor—acceptance of substandard work [11]
- Lack of collaborative R&D for systems [8]
- No process for discovery of interactive effects of new products [4]

### Overarching Barriers

- Lack of education/awareness
- Non-systems approach to building envelope construction
- Skilled labor shortage
- Absence of total system performance measurement for the building envelope
- Difficulty for new and emerging technologies to achieve building code acceptance

Examining the state of the industry, identifying trends, and considering difficulties and potential opportunities led participants to define a sizable number of market, policy, and technology barriers. These were summarized as five major challenges.

#### Barrier 1

##### Lack of education/awareness

Industry fragmentation perpetuates information fragmentation and vice versa. Researchers are not informed about industry structure and marketplace needs. Product manufacturers, architects, designers, engineers, builders, contractors, and code officials need to be able to technically assess the characteristics of new products, materials, and systems. They also need to know proper installation and operating methods. Consumers and homeowners need information that will enable them to generate demand for the 2020 vision and influence builders' decisions.

\* Numbers in brackets indicate vote tallies on barrier priority by roadmap workshop participants.

### CONSTRUCTION INDUSTRY VALUE CHAIN



*Education across the construction industry value chain is crucial to the success of the vision.*

Education and awareness are critical to unifying a complex industry in moving toward the vision. A two-way feedback loop between research and marketplace needs would help ensure that research is grounded in marketplace needs and that new products succeed in the marketplace.

**Barrier 2**  
**Non-systems approach to building envelope construction**

Many failures in building envelopes occur at the interfaces<sup>10</sup> of products made by different companies or manufacturers and installed or repaired on-site by a variety of different trades. While the individual parts in complex building envelope assemblies must retain their integrity (for design variety, legal accountability, and future replacement considerations), interface complexity needs to be simplified. Development of clear assembly protocols for installation, replacement, and repair of subsystems would benefit all industry segments. A wealth of innovative materials, systems, and processes is currently available for enhanced building envelopes, but these resources are not utilized as fully as they could be. Collaborative R&D would establish a solid platform on which a systems approach to the design and

construction of the building envelope could be established. Collaborative R&D should be emphasized within each vision element, with cognizance of the potential synergies and pitfalls created by the interactions between the vision elements.

**Barrier 3**  
**Shortage of skilled labor**

The shortage of skilled labor within the construction industry has been exacerbated by the combination of high construction demand and low national unemployment. Builders

are increasingly forced to employ inexperienced workers, which lengthens the construction schedule and may lead to improper installation of components.

Even though the number of skilled workers has grown 5 percent annually since 1990 (3.9 million in 1999) an additional 240,000 skilled workers per year are needed.<sup>11</sup> Furthermore, future prospects are dim, as the number of high school students entering the trades declines.



<sup>10</sup> Interfaces: connections between parts that physically meet.

<sup>11</sup> Knight Ridder/Tribune Business News, February 29, 2000.

**Barrier 4****Absence of total system performance measurement**

Consumers are faced with an overwhelming amount of information, multiple experts, and a short decision-making time frame when purchasing a home. No comprehensive guide exists to support the choices of consumers making this significant decision.

A simple, user-friendly, voluntary rating system is needed to assess and communicate the performance of a building envelope on multiple attributes (e.g., the elements of the 2020 vision). The rating criteria should be objective and scientifically based. Such a metric analysis product would enable consumers and designers to make more intelligent decisions and would serve as a powerful marketing tool for builders and building product manufacturers.

Industry believes that the widely diverse information needed for developing a useful performance measurement makes this project particularly appropriate for government involvement.

**Barrier 5****Difficulty for new and emerging technologies to achieve building code acceptance**

To protect public health and safety, building regulations establish minimum criteria for building designs and construction. Regulations are based on model building codes developed in the voluntary sector, principally by three regional organizations: Building Officials and Code Administrators International, Inc. (BOCA); the International Conference of Building Officials (ICBO); and the Southern Building Code Congress International, Inc. (SBCCI). The International Code Council (ICC), made up of the previous three, will eventually become the single nationwide building code, replacing the three regional model codes.<sup>12</sup>

Model codes tend to be prescriptive, but they accept new designs, processes, and products if code requirements are met on the basis of equivalent performance. However, the lack of product testing, standards, and familiarity can inhibit the approval process. In addition, if not specifically covered in the code, each State or local enforcement authority will be faced with independently assessing the acceptability of a new technology on a performance equivalency basis. This tends to delay a new technology's entry into the market.<sup>13</sup>

<sup>12</sup> Currently the issue is adoption and enforcement of such a code by State and local governments on a uniform basis, which will occur over the next few years as ICC codes are adopted in place of regional codes.

<sup>13</sup> David Conover, National Evaluation Service (personal communication), August 2000.

## STRATEGIES

### MAKING IT HAPPEN

Achieving the vision will require a parallel strategic approach: market/policy strategies to surmount key barriers to innovation and technology strategies to exploit expanded use and new directions in materials, products, systems, design processes, and construction practices. The five market/policy strategies were developed by industry working groups, while the detail for the one overarching technology strategy was gathered from a broader industry group through an industry survey.

Considering the 20-year goal for the vision, the roadmap approach must concentrate both on better use of current materials and proven technologies as well as longer-term technology innovation. Market/policy actions generally focus on better and more widespread use of currently known technologies and have an immediate impact in the marketplace. Technology R&D is critical to the innovative technical advances that are needed to meet the vision.

#### Market/Policy Strategies

1. Promote education/outreach along the construction value chain.
2. Build a platform for collaboration in R&D leading to systems approach and improved envelope construction.
3. Expand skilled workforce trained in labor-reducing technology.
4. Develop a building envelope performance rating system.
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#### Overarching Technology Strategy

Develop, evaluate, and promote the adoption of building envelope materials, systems, and process/design techniques, aligned with one or more of the vision elements.

## STRATEGIES

### STRATEGY 1: Promote education/outreach along the construction value chain.

**Barrier:** Lack of education/awareness

**Result:** All members of the construction supply chain make informed decisions aligned with the 2020 vision.

#### *Near term (3 years)*

Establish working group:

- Leadership for education should comprise integrated industry/government/university team
- Develop strategy and mission for education across the value chain.
- Provide national oversight and regional focus across the construction supply chain.

Scope and audience:

- Develop strategy and vision for education across the construction supply chain.
- Define scope and audience (designers, builders, building product manufacturers, consumers).

Best practices:

- Research existing/emerging education efforts across the construction supply chain.
- Document “lessons learned” by individuals and organizations involved with education.

Technical areas:

- Determine technical areas for educational focus on a regional basis.

#### *Mid to long term (10-20 years)*

Leverage awareness and funding for education across the construction supply chain.

Develop and deploy strategic educational thrust:

- Determine gaps in education by audience and technical area.
- Leverage existing programs to fill gaps.
- Develop new education programs to fill gaps where there are no existing programs.

Technology transfer:

- Coordinate and manage technology transfer to meet educational thrust.
- Ensure that successful programs are replicated across the country.
- Ensure balance of education across supply-chain.
- Have “off-the-shelf” packages ready for mass distribution.

### SUGGESTIONS FOR EDUCATION/OUTREACH

Across the construction value chain:

- Educate all members on the importance of the vision elements and measures for implementation.
- Develop and distribute to industry, up-to-date envelope design information, packaged in best practice guides and knowledge tools (such as specifications or decision matrices) to transfer the ideas.

- Develop a building envelope rating system for marketing to consumers (see Strategy 4).
- Increase dialogue between industry members and code officials to ensure acceptance of technologies by appropriate codes. Education should include information about codes, standards, and other institutional issues, and suggestions for dealing with those issues during technology RD&D (see Strategy 5).

R&D and product manufacturing:

- Increase collaborative R&D as a platform for systems approach (see Strategy 2).

Designers, architects, engineers, builders, contractors:

- Develop a “Teach the Teachers” program.
- Monitor the implementation of new technology. Install process for continuous improvement; reward leadership.
- Support development of continuing education programs for professionals in energy technologies and building intelligence.
- Develop and disseminate a procurement strategy for the contracting of architectural and design services that rewards architecture and engineering for the additional analysis and design effort needed to achieve superior building performance.
- Publish “plain talk” guides to best practices for envelope construction (drawings and multilingual).
- Increase skilled labor supply (see Strategy 3).

Consumers, homeowners, real estate:

- Educate homeowners on how to prolong the life of home building materials.
- Educate homeowners about energy consumption.
- Include consumers in product development ideas and educate on social, environmental, and economic impacts.
- Develop a “build your own house” concept that would provide consumers with the ability to build and evaluate their own homes on the Internet.
- Use television programs to link homeowners with current research.

## ROADMAP IMPLEMENTATION

The process for implementing each market/policy strategy will follow these general guidelines:

- Identify leadership, recruit champions, establish steering group.
- Develop strategic vision, mission, goals, and target audiences.
- Research existing best practices and resources.
- Identify gaps to be filled.
- Ensure continuous improvement through monitor and feedback cycles and adjustments.

## STRATEGY 2: Build a platform for collaboration, leading to a systems approach and improved envelope construction.

**Barrier:** Non-systems approach

**Result:** Increased collaboration in R&D leading to systems approach and improved envelope construction.

### Near term (3 years)

Establish working group:

- Leadership for collaborative R&D should be integrated industry/government/university team.
- Develop strategy and mission for collaborative R&D.
- Provide national oversight and regional focus.

Best practices:

- Develop and analyze 15 to 20 case studies of collaborative efforts. Include project overview, scope and outcome, parties involved, budget, evaluation, and success characteristics.
- Determine incentives and barriers to collaborative efforts, e.g., antitrust legislation, market demand for quality, ownership of intellectual property, accomplishments in other countries, education of experts.

Technical areas:

- Determine technical areas for collaborative R&D on a regional basis.

### Mid to long term (10-20 years)

Improve environment for collaboration:

- Create environment “friendly to collaborative R&D” based on best practices from case studies, barriers, and incentives.

Conduct R&D:

- Prioritize and begin R&D.
- R&D should be coordinated nationally and have a regional focus.

Technology transfer:

- Develop knowledge products that synthesize output of collaborative R&D and can be used by a mass audience (e.g. best practice guide).
- Link knowledge products to training.
- Technology transfer should be coordinated nationally and have a regional focus.

## SUGGESTIONS

Priority technical areas where collaborative R&D would advance the establishment of a systems approach include:

- Intelligent Building Materials (advanced polyvalent materials, self-adjusting/repairing materials)
- Design for Adaptability (product design for assembly/disassembly, replacement/repair, recyclability)
- Disaster Resistance

- Envelope Component Integration (product interfaces, component integration)
- Moisture (detection and resistance)
- Advanced Panel/Prefabrication
- Modular Coordination
- Design Tools (CAD)
- Resource-Efficient Materials (many older, natural technologies—currently in the public domain—are good candidates for collaborative research)

Existing efforts should be leveraged as much as possible. A preliminary list of resources includes:

- Building America, a public/private partnership between U.S. industry and the U.S. Department of Energy, provides “energy solutions for production housing.” Teams of architects, engineers, builders, and building product manufacturers work together using a systems approach to build homes that are up to 50 percent more energy-efficient than conventional residential construction.<sup>14</sup>

- The Partnership for Advancing Technology in Housing (PATH) is the only public/private partnership between the home building industry and the Federal agencies committed to residential technology that integrates the broad range of technology issues—affordability, energy-efficiency, environmental impact, hazard mitigation, labor safety—into one plan. PATH improves home building technology through research in all these areas, through information dissemination to product manufacturers, homebuilders, and homeowners, and through technology and housing policy work.
- The Building Envelope Research Consortium (BERC) in Vancouver, Canada, created a Best Practice Guide (BPG) for each construction system type. Published by Canada Mortgage and Housing Corporation (CMHC), the guides are designed for architects, engineers, and construction companies.<sup>15</sup>
- The Consortium for Moisture Management for Exterior Wall Systems (MMEWS), a successful collaborative R&D project sponsored by the Canadian Institute for Research in Construction, could be an excellent case study.<sup>16</sup>

<sup>14</sup> U.S. Department of Energy, [http://www.eren.doe.gov/buildings/building\\_america/](http://www.eren.doe.gov/buildings/building_america/), September 2000.

<sup>15</sup> Don Hazleden, MAIBC MRAIC, British Columbia-Building Envelope Research Consortium, August 2000.

<sup>16</sup> Institute for Research in Construction, <http://www.nrc.ca/irc/bes/mews/overview.html>, August 2000.

**STRATEGY 3: Expand skilled workforce trained in labor-reducing technology.****Barrier:** Skilled labor shortage**Result:** Adequate skilled workforce trained in labor-reducing technology.***Near term (3 years)***

Establish working group:

- Identify five key trades within the building envelope that need skilled labor.
- Work closely with the key associations for each trade.
- Pick a focus area for initial pilot, that will yield a “short, quick win” (e.g., insulation contractors in the Northeast).

Determine best practices:

For labor in a specific industry focus area—

- Develop inventory of existing training programs and actions to address skilled labor.
- Establish baseline of best practices of existing training programs and curriculum.
- Define and prioritize the knowledge, skills, and abilities required of a practitioner.
- Define best practices for labor and establish a database; best practices should be backed by performance testing.

***Mid to long term (10-20 years)***

Increase attractiveness and entry into trades:

- Work with all levels of education: high school, apprentice programs, vocational schools, existing labor, supervisors.
- Build image of trade as career choice.
- Determine best practices and strategy for labor recruitment.

Develop labor-reducing technology:

- Conduct research and development of technologies for retrofit and new construction markets.

Develop training and third-party certification:

Working with specific trade association and key stakeholders—

- Develop curriculum and “hands-on” skill development in accordance with best practices.
- Develop “instructor version” of curriculum for “train the trainers” program.
- Determine third party to perform certification and define criteria for certification.
- Provide incentives for participation in training and certification.\*

\* Dave Simanoff, “Builders Across the Country Feel Skilled-Labor Crunch,” KRTBN Knight Ridder/Tribune Business News, February 29, 2000.

**SUGGESTIONS**

Expanding the nation’s skilled labor pool is a broad issue involving needs and interests from many quarters. Numerous public and private organizations are dedicated to developing the U.S. workforce. One large opportunity to increase skilled labor involves high-profile career recruitment, in collaboration and coordination with existing skilled labor organizations such as:

- American Association of Community Colleges
- Associated Builders and Contractors
- Association for Career and Technical Education (ACTE)
- Consortium of Community Colleges
- D.C. Metropolitan Subcontractors Association
- Home Builders Institute
- Institute for Business & Home Safety (IBHS)
- International Applied Arts and Science Institute
- NAHB Research Center
- National Association of VoTech Directors (NASDVTEC)
- National Center for Construction Education Research
- National Environmental Training Association
- National Skills Standards Board
- PATH

- U.S. Department of Education
- U.S. Department of Labor—Job Corps
- The Vocational Industrial Clubs of America, Inc. (SkillsUSA-VICA)
- Vocational Evaluation and Work Adjustment Association

Along with recruitment, a concentrated effort to deploy technologies that reduce and/or simplify on-site labor could be undertaken, leading to enhancement of the image of the trades as well as better quality assembly and build processes. Accelerating RD&D on the technologies below could lead to better labor capabilities at building sites:

- Advanced framing
- Modular coordination
- Advanced panel/prefabrication (walls, roof, foundation)
- Envelope component integration
- Diagnostic tools (e.g., for testing correct installation)
- Design tools (pre-site activity that could impact on-site work)

Support and incentives—in the form of grants, tax breaks, insurance reductions—could also be offered to builders and contractors to encourage the use of trained labor or to adopt a training program. Higher wages and better benefits will also be key to attracting and keeping career-minded skilled trades workers.

Existing efforts should be leveraged as much as possible. A preliminary list of resources includes:

- A 10-year Renaissance Project was launched in April 2000 to develop an International Applied Arts and Science Institute (IAASI). IAASI's mission is to create a comprehensive, knowledge-based educational program for the construction trades through America's community colleges to increase the number of qualified, professional workers and to improve the quality of construction through national standards and certifications. Under development by a consortium of nine community colleges, IAASI plans to raise \$2.8 billion through industry partnerships and the DreamStreets Foundation, have a pilot

curriculum by 2003, and establish regional centers in every State by 2010.<sup>17</sup>

- To transfer best practices in insulation installation, CertainTeed Corporation developed a certification program for installers through the NAHB Research Center. Results have been very positive.<sup>18</sup>
- Habitat for Humanity brings skilled and unskilled workers together, providing an excellent opportunity to introduce high-school students to the trades and to prototype new ideas.<sup>19</sup>
- SkillsUSA, an association of students and teachers in the trade, technical, and skilled service occupations, has begun a campaign to bring national attention to the importance of skilled labor.

<sup>17</sup> Gail B. Kettlewell, "International Applied Arts and Sciences Institute: The Renaissance Project," August 2000.

<sup>18</sup> Tom Newton, CertainTeed Corporation (personal correspondence), August 2000.

<sup>19</sup> Thom Martson, Habitat for Humanity (personal correspondence), August 2000.

**STRATEGY 4: Develop a building envelope performance rating system.****Barrier:** Absence of total system performance measurement**Result:** Widely accepted set of tools that provides easily understood information on the performance of the building envelope and allows the performance rating of the building.***Near term (3 years)***

Scope and audience:

- Develop strategy and vision.
- Clearly define scope (residential building envelope).
- Define audience (designers, builders, building product manufacturers, consumers).
- Conduct market research.

Determine attributes and capabilities:

- Attributes of the rating system should be based on the vision elements and prioritized according to market research.
- Capabilities of the rating system should ensure its acceptance in the industry.

Best practices:

- Research current and emergent rating systems and measurement tools.
- Classify by audience, building scope, and attributes.
- Document “lessons learned” by individuals and organizations involved with rating systems.

***Mid to long term (10-20 years)***

Continue building audience:

- Engage key stakeholders throughout process to ensure acceptance.

Develop rating system:

- Determine elements of existing systems that satisfy desired attributes and capabilities.
- Define and begin research needed to fill gaps between existing and desired rating system.
- Synthesize desired features into comprehensive, technically accurate rating system.
- Rating system should be developed one element at a time (with priority elements first). Elements should have a consistent “output” or metric.

Technology transfer:

- Develop a transparent, accessible, simple-to-use set of tools and information (see Performance Rating System, page 19).
- Provide incentives or requirements to participate.
- Provide a clear distinction and relationship to other rating systems.
- Begin a well-funded, coordinated market transformation program.

Collect data:

- Collect appropriate data for system attributes from manufacturers and industry groups.
- Assemble data into database of products, assemblies, and construction type (via graphical interface).
- Fill gaps in data through calculation and testing.
- Make database available to users.

**SUGGESTIONS**

Accelerating RD&D on the following technologies would contribute to the timely development of a building envelope performance rating system:<sup>20</sup>

- Design for adaptability
- Design tools
- Envelope component integration
- Performance modeling/testing
- Performance monitoring/testing
- Performance rating criteria

<sup>20</sup>American Standards for Testing and Materials (ASTM) is also mounting an effort to meet the need for standardized evaluation tools, which may overlap the Building Envelope vision attributes. See Performance Criteria for Dwellings, ASTM E06.66, January 12, 2000.

## POTENTIAL PERFORMANCE RATING SYSTEM ATTRIBUTES

Vision Element	Suggested Measurement	Suggested Resources
<b>Adaptable</b>	<ul style="list-style-type: none"> <li>Ability to change components/rooms</li> <li>Designed for adaptation</li> </ul>	<ul style="list-style-type: none"> <li>Centex Homes (House of the Future)</li> </ul>
<b>Affordable</b>	<ul style="list-style-type: none"> <li>Monthly housing cost</li> <li>First cost</li> <li>Maintenance cost</li> <li>Life-cycle cost</li> </ul>	<ul style="list-style-type: none"> <li>ASTM Standards on Building Economics BLDGEC99</li> <li>ASTM Standard on Life-Cycle Cost</li> <li>NIST life-cycle cost methodologies for process and design</li> </ul>
<b>Durable</b>	<ul style="list-style-type: none"> <li>Performance of components and systems by climate</li> <li>Resistance to wind, earthquakes, fire, weathering (moisture), pests, maintenance</li> </ul>	<ul style="list-style-type: none"> <li>NES Durability Protocol for building products and assemblies</li> <li>Institute for Business &amp; Home Safety (IBHS)</li> <li>NIST</li> <li>ASTM C632 Test for Durability</li> </ul>
<b>Energy</b>	<ul style="list-style-type: none"> <li>Energy efficiency: energy consumption per month</li> </ul>	<ul style="list-style-type: none"> <li>CertainTeed (Certified Plus Home)</li> <li>ENERGY STAR</li> <li>Louisiana Pacific (guarantee for life program)</li> <li>ASTM Guarded Hot Box Standard</li> <li>Whole Wall Thermal Performance Calculator</li> <li>Southface Energy Institute</li> </ul>
<b>Environment</b>	<ul style="list-style-type: none"> <li>Life-cycle assessment for embodied energy and raw materials</li> </ul>	<ul style="list-style-type: none"> <li>ASTM E50 committee on life-cycle standard (used by BEES)</li> <li>ISO standards</li> <li>SBIC (residential rating system)</li> <li>ECCO (Environmental Conference of Concrete Organizations)</li> <li>USGBC (LEEDS)</li> </ul>
<b>Health/Comfort</b>	<ul style="list-style-type: none"> <li>Indoor air quality (PPM): mold, radon, lead, VOCs, formaldehyde</li> <li>Acoustics</li> <li>Thermal comfort: ambient air temperature, mean radiant temperature, humidity, air speed</li> </ul>	<ul style="list-style-type: none"> <li>ASHRAE application guide for IAQ standards of performance; standard 62 on ventilation; standard 55-1992 for thermal comfort</li> <li>EPA</li> <li>American Lung Association</li> <li>An inexpensive test for 3 to 4 IAQ measurements is needed</li> </ul>
<b>Intelligent</b>	<ul style="list-style-type: none"> <li>Degree of interaction (sensor/reaction) between house components, occupants, and external environment</li> </ul>	<ul style="list-style-type: none"> <li>Window research</li> </ul>

A successful performance rating system for building envelopes would have these characteristics:

- Consumer Report style
- Quick and easy to use
- Inexpensive
- Feasible in large-scale applications
- Providing marketing advantage
- Supporting deployment of emerging technologies
- Acceptable to industry, appraisers, and insurers

To be effective, the performance rating system should be accessible via:

- Website
- Publications
- Interactive self-guided computer rating tool
- Training workshops
- Outreach to key organizations

**STRATEGY 5: Support the acceptance of emerging technologies by Codes and Standards.****Barrier:** Difficulty for new and emerging technologies to achieve building code acceptance**Result:** Quicker adoption and acceptance of emerging technologies.**Near term (3 years)**

Support emerging technologies:\*

- Develop strategy and vision in supporting the acceptance of emerging technologies.
- Develop group to support emerging envelope technologies. Group might be subdivided into envelope components: walls, roofs, ceilings, etc.
- Provide ongoing dialogue with code officials.

Support a single, nationwide building code (such as ICC) incorporating both prescriptive and performance-based standards.

Support a central point for evaluation.\*\*

Support increased linkage between codes/standards and basic research.

**Mid to long term (10-20 years)**

Develop test procedures:

- Provide a resource for gaining appropriate tests.

Develop standards:

- Provide a resource for development of appropriate standards.

Ensure code acceptance:

- Work with product designers/manufacturers and code officials throughout product development to educate and ensure acceptance of technologies by appropriate codes.

\* Emerging technology support should include an opportunity for dialogue between the researchers, builders, contractors, code officials, and others in the development and delivery scheme, before, during, and after RD&D.

\*\* New products, designs, technologies, and building systems can currently be evaluated with respect to the regional model codes by the Evaluation Service of each of the individual organizations, or by the National Evaluation Service (NES), which covers all the regional model codes as well as the ICC codes. Currently the regional evaluation reports enjoy widespread acceptance where the regional model code is adopted and the NES enjoys widespread acceptance throughout the U.S. In addition, NES activities with the World Federation of Technical Assessment Organizations and the development of reciprocal agreements with NES counterparts in other countries will facilitate global acceptance of new building technology. PATH is sponsoring a special evaluation package through the NES to fund the evaluations of residential building technologies.

**SUGGESTIONS**

A number of efforts can be made to support the acceptance of emerging technologies by Codes and Standards officials. Many of the technical areas identified for research and development will not win immediate regulatory approval. First they must be compared to similar (already approved) tech-

nologies in order to determine which codes and standards will be applicable.

Existing resources should be mined for methodologies that could support building code acceptance of new technologies. For example, the California Universities for Research in Earthquake Engineering (CUREe)

is studying ways to reduce earthquake losses due to wood frame construction. The project will link testing, analysis, and field research to building codes and standards.<sup>21</sup>

<sup>21</sup> CUREe Woodframe Project, [http://www.curee.org/Projects/Woodframe\\_Project/woodframe\\_project.html](http://www.curee.org/Projects/Woodframe_Project/woodframe_project.html), September 2000.

**STRATEGY 6: Develop, evaluate, and promote the adoption of building envelope materials, systems, and process/design techniques, aligned with one or more of the vision elements.**

***Near term (3 years)***

- Initiate joint industry/government technology implementation steering group.
- Determine high-priority technical activities (based on vision contribution and collaboration needed).
- Investigate current market status of priority technical activities (what has already been done/what is being done at other research organizations).
- Determine champions for priority technological activities (DOE, other government, government/industry, industry).
- Increase research funding for priority technical activities (DOE program alignment and competitive solicitation).
- Develop critical 20-year technology and implementation plan pathway (milestones, funding, thrusts) to produce a balanced portfolio of priority technical products.
- Market feedback should be gathered at regular intervals to assess current demand for the technical priorities; adjustments should be made accordingly.

***Mid to long term (10-20 years)***

- Technology transfer for all materials, systems, process/design tools, and performance evaluation results should occur continuously over the 20-year span. Outreach should include the translation of research results into conceptual design, demonstration, and knowledge products (architectural blueprints, building standards, manuals, and fact sheets).
- Industry partners should be prepared to manufacture and market materials/systems once a technology has reached the pilot/demonstration stage.
- Develop, test, and promote the adoption of materials and systems aligned with one or more of the vision elements through RD&D.
- Develop gateway/information outreach thrust for the deployment of process/design tools; initiate the development of new process/design technical products.
- Evaluate performance of existing and new emergent materials and assemblies.

**SUGGESTIONS**

Through a survey of more than 300 industry members, 120 unique technical research activities were identified that could move the industry toward its vision. These activities (outlined on pages 23-26) form the

basis of the technology strategy. The activities were rated on potential contribution toward each element of the vision, the investment required, and the certainty of success. They reflect industry needs as well as the potential direction for

basic, proof-of-concept, and commercialization RD&D. The list of activities is not meant to be comprehensive; rather, it highlights issues of importance to the industry and to design and construction professionals.

Grouped in 35 categories, the technology research needs fall into four RD&D areas necessary to achieve the 2020 vision:

- **Materials**—Potential for greater energy efficiency, control performance, cost reduction, environmental consideration, and ease of construction and maintenance through innovative materials.
- **Systems**—Addresses innovations within envelope components and assemblies, considering the envelope as a complex, multi-layered, integrated part of the building.
- **Design and construction process**—Technologies and processes that minimize materials, energy, time, and expense through better design, specification, construction, and operation and maintenance of the building envelope.
- **Performance evaluation**—Processes to successfully conduct and manage modeling, monitoring, and rating the performance of the building envelope with regard to moisture, solar radiation, temperature differential, pressure differential, wind pressure, and impact and catastrophic failure.

All the technical research activities listed contribute positively to at least one of the vision elements. The Industry Survey Results matrix on page 23 shows how the different categories intersect with each of the vision elements. Certain research areas impact multiple elements, e.g., the “Design Tools” category supports five of the seven elements. These include activities such as:

- Moisture research/materials
- Air/vapor barriers
- Envelope component
- Design tools
- Performance modeling, monitoring, and rating criteria
- Intelligent building materials, systems, super walls
- Advanced panel

Other research areas are crucial to the success of a specific element and should be considered high priority regardless of their applicability. One such critical area is “Design for Adaptability,” on which the Adaptable element depends.

Other high-priority technical activities include:

- Advanced framing
- Performance modeling, monitoring, and rating criteria
- Advanced insulation and energy services
- Resource-efficient materials
- Daylighting, nontoxic materials, IAQ
- Intelligent building materials and systems

*The Industry Survey Results matrix (page 23) offers a quick reference point for clarifying which technical activities contribute to which vision elements. Organizations may use the matrix to identify activities based on their area of research expertise, or to determine where to assign R&D resources in pursuit of a particular vision element. For example, DOE may decide to focus research in those areas that support energy-positive technology.*

## INDUSTRY SURVEY RESULTS

MATERIALS	Adaptable	Affordable	Durable	Energy-Positive	Environmental	Healthy/Comfortable	Intelligent	Applicable in Retrofit
Air Vapor Barriers		•	•	•	•	•		•
Advanced Insulation		•		•	•			•
Advanced Aggregate Materials				•				
Disaster-Resistant Materials		•				•		•
Moisture-Control Materials		•		•		•		•
Nontoxic Materials					•	•		•
Radiant Technologies				•				
Resource-Efficient Materials		•		•	•			•
Cellular Building Components	•		•	•				
Fabric Technology			•	•			•	•
Intelligent Building Materials	•		•	•	•	•	•	•

SYSTEMS	Adaptable	Affordable	Durable	Energy-Positive	Environmental	Healthy/Comfortable	Intelligent	Applicable in Retrofit
Rain Screen				•	•			
Double Envelope				•				
Advanced Foundations		•	•					
Crawl Spaces		•	•		•			•
Energy Services/Supply				•	•			•
Envelope Component Integration	•	•	•		•			•
Roof/Attic Systems		•	•		•			•
Advanced Panel/Prefabrication	•	•	•	•	•			
Intelligent Envelope Systems				•			•	
Super Walls			•	•			•	•

PROCESS / DESIGN	Adaptable	Affordable	Durable	Energy-Positive	Environmental	Healthy/Comfortable	Intelligent	Applicable in Retrofit
Daylight/Passive Solar Design			•	•	•	•		•
Advanced Framing		•		•	•			
Design Tools	•	•	•		•	•		•
Design for Adaptability	•				•			
Modular Coordination	•	•	•		•			
Natural Ventilation/IAQ		•	•		•	•		
Recycling/Reuse Processes		•			•			•
Regional Design		•	•		•	•		•
Automation		•		•				
Design for Intelligence			•	•	•	•	•	

PERFORMANCE	Adaptable	Affordable	Durable	Energy-Positive	Environmental	Healthy/Comfortable	Intelligent	Applicable in Retrofit
Performance Modeling/Testing		•	•	•	•	•		•
Performance Monitoring/Testing		•	•	•	•	•		•
Performance Rating Criteria		•	•	•	•	•		•

☐ Low Risk: Few technical unknowns; within respondent's R&D budget
 ☐ Medium Risk: Some technical unknowns; some co-funding
 ☐ High Risk: Many technical unknowns; significant co-funding

## DETAILED TECHNICAL RD&D ACTIVITIES

### MATERIALS

#### *Advanced Aggregate Materials*

- Develop innovative aggregate substitutes for weight reduction and thermal insulation in cast-in-place and precast concrete.

#### *Advanced Insulation*

- Develop environmentally friendly super-insulations.
- Develop high-thermal/low-volume, durable, energy-efficient envelope components.
- Develop simple installation systems for advanced (high R-value) insulation.
- Develop economical manufacturing processes for advanced (high R-value) insulation systems.
- Sponsor research to provide a better understanding of R-values in aged insulation materials.

#### *Air/Vapor Barriers*

- Develop air barrier concept integrated into thermal envelope assembly.
- Develop a diodic vapor barrier for use in mixed climate regions.
- Develop a spray-on coating for building joints/seams that restricts water/air penetration and is easy to apply.
- Develop an easy-to-use factory-applied gasket to air-seal multisection HUD code or modular homes. Gasket to seal 1/4" to 1/2" gaps.
- Develop OSB (oriented strand board) which will have high vapor permeability and high decay resistance.

#### *Cellular Building Components*

- Research latent performance attributes of cellular morphologies in a variety of building components, including exterior wall assemblies, interior wall surfaces and substrates, roof assemblies, floor assemblies, structural components, and other elements.
- Explore the benefits and performance attributes of various raw materials that can be used to fabricate advanced cellular building components. Evaluate the potential of cellular morphologies in the areas of aggregate materials, insulation, wood, air, and vapor barriers, and disaster-resistant materials.

#### *Disaster-Resistant Materials*

- Develop ignition-resistant super-insulation materials for building envelope.
- Develop an interior finish wall panel of a composite material class with embedded fibrous or other fire-monitoring material capable of detecting fire spread and alerting residents. Coordinate interior wall panel and central fire alarm or distributed alarm systems. In this instance the central alarm system would be made redundant. All fire detection and alarm functionality would be satisfied by the panel itself.

#### *Fabric Technology*

- Develop fabrics composed of capillary fibers of self-healing resins designed to form patches over areas that have been damaged.
- Invest in research toward the use of fabrics within orthogonal, panelized frameworks with integral insulation, and explore the possibility for on-site rigidizing fabric surface.

- Study impact resistance of high-strength fabrics and various "woven" technologies for use as exterior sheathing or interior reinforcement.

Counteract positive and negative air pressure with fabric wall reinforcement. Reduce or eliminate catastrophic failures with selective textile reinforcements of wall and roof assemblies.

#### *Intelligent Materials (Self-Adjusting/Regulating/Repairing/Polyvalent)*

- Develop self-righting structures and other types of "responsive" structures to eliminate damage to exterior wall and interior finishes due to differential settlement and other types of short- and long-term building movement.
- Create a material and/or assembly with variable gas permeability that adjusts to exterior environmental conditions. User control bypass is also an important performance requirement.
- Produce variable R-value insulating material capable of adjusting the interior insulation's effective R-value, thereby allowing heat transfer to be regulated by changing diurnal peaks.
- Develop self-healing building materials—materials that have a variety of self-healing properties, that is, the ability to repair damage and or inconsistencies that could compromise the performance of that material. Self-healing materials could minimize construction and repairs waste, improve quality through "embedded" control mechanisms and facilitate crews in the tasks of detecting failures or problems.
- Create self-healing insulation materials—evaluate the combined use of expanding agents with cellular materials to provide self-healing properties for the insulation matrix.
- Design wall assemblies and details that effectively collect incidental moisture into a safe storage location or dispose of it safely.
- Develop highly polyvalent composite-material systems able to satisfy complex and multivariate performance requirements of architectural assemblies.
- Create a series of modular wall units displaying variable thermal attributes while maintaining or increasing their durability.
- Develop classes of polyvalence materials with embedded information-technologies functionality.

#### *Moisture-Control Materials*

- Develop building materials and/or products that can be applied to inhibit mold growth.
- Develop materials to provide cladding and protection under different climatic conditions.
- Design wall systems with improved resistance to water penetration.
- Develop breather-type sheathing membranes to act as moisture and air barriers, have a 100-year service life, and effectively integrate with other components of the building envelope.

#### *Nontoxic Materials*

- Create new materials that reduce or eliminate allergic and other reactions among people with sensitivities and thus improve indoor air quality.

#### *Radiant Technologies*

- Develop, refine, and promote radiant barrier technology for residential wall assemblies for hot climates.
- Develop better radiant metal deck assemblies.
- Test various types of radiant barriers in roofs and attics in combination with various shades of roof color. Document effectiveness and payback times.
- Research impacts of radiant heat loads in attics.

#### *Resource-Efficient Materials*

- Produce panelized enclosure systems composed of alternative and/or recycled materials such as recycled plastics, straw, and fly ash combined with traditional materials such as concrete, wood, or steel.
- Promote the development and adoption of panelized building materials that combine structural and energy-efficient properties with the use of recycled or waste resources such as waste agricultural products; e.g., Strawmit brand compressed straw panels. Research solutions to issues such as moisture- and fire-resistance.
- Develop recycled roof coverings with performance attributes comparable to or higher than those of new products or materials.
- Produce alternative materials using recycled and/or waste material such as:
  - Viable exterior wall panels composed of cellulose and lignin-based natural fibers reinforcing a natural resin matrix (e.g. agriculture fiber composite exterior wall panel).
  - Lightweight natural-fiber-reinforced cementitious panels for stress-skin exterior wall applications. Natural fibers—such as straw, wheat, and other agricultural products—provide structural and thermal resistance properties.
  - Biomaterial-mediated exterior wall and roof assemblies. Support research focused on the potential integration of natural or "green" materials into exterior wall and roof assemblies of small structures, particularly residential buildings.
- Develop guidelines and standards for the performance requirements of recycled materials and products.
- Research alternative processing methods and practices that can reduce the cost of recycled materials.

## SYSTEMS

#### *Advanced Foundations*

- Develop foundations that are low energy losers, impervious to moisture and insects, natural disasters, and a variety of soil conditions.

#### *Advanced Panel/Prefabrication*

- Develop building enclosures and structural systems composed entirely of 2- and 3-dimensional composite panel and structural element technology.
- Support for projects that eliminate the proliferation of discrete building components and minimize complexity while maximizing the variation and flexibility, durability, and cost-effectiveness of building systems utilizing composite panel technology.
- Create automated manufacturing techniques to mass-produce wall panels of new or nontraditional raw materials.
- Develop pre-manufactured building enclosure panels. Panels might be designed with an underlying modular dimensioning approach to minimize waste of materials while allowing for easy handling by two workers.
- Research the downstream costs of call-backs, warranties, repair, and upkeep resulting from excessive dependence on on-site labor for installation of separate parts, in contrast to prefabrication at off-site plants.

#### *Crawl Spaces*

- Research effective insulation techniques for open-web truss floor systems.
- Research energy, moisture, and IAQ impacts of vented versus unvented crawl spaces.

#### *Double Envelope*

- Develop glass and opaque double-envelope systems with integral energy collection and distribution. These systems combine two or more layers separated by one or more cavities for the purpose of collecting and utilizing (winter mode) or rejecting (summer mode).

#### *Energy Services/Supply*

- Develop building dehumidification using heat from building envelope.
- Develop roof and/or wall assemblies that collect and supply energy to the building envelope.
- Develop wall systems that integrate photovoltaics, similar to new roof shingles.
- Develop roofing systems that produce energy through PV-capture heat for space heating or water heating.
- Integrate photovoltaic circuiting, piping, waterproofing, insulation, and textured interior surface.
- Develop thermally driven air conditioning system using solar heat from the envelope.
- Research technologies for the production of energy-generating exterior walls.
- Develop simple, mass-producible wall and roof systems that can act as solar thermal collectors.
- Develop nontraditional solar thermal space heating using the building envelope.
- Generate low-cost thermal storage with air heat exchanger using the building envelope.

#### *Envelope Component Integration*

- Create enclosure assembly techniques that go beyond conventional systems interfacing to true integration. For example, wall assemblies that also serve as HVAC system supply or return ducts; foundations that can be part of an on-site rainwater collection and storage system.
- Develop window, door, and other envelope-penetration systems that are leak-proof and reduce envelope's discontinuities.
- Develop improved industry standards for the full range of building envelope product interfaces through collaborative R&D and targeted economic incentives.
- Develop effective, environmentally acceptable joint closures (e.g. window/wall interfaces; durable, air-tight sealing mechanism for exterior door).
- Create innovative building envelope (walls, windows, and roof) components to optimize the energy-efficiency of buildings in different climate zones.
- Support projects that simplify construction of the envelope and its components.

#### *Intelligent Envelope Systems*

- Develop intelligent object data format standards, in partnership with NIST. Goal is standard for data type, location, to facilitate seamless integration between DOE 2/blast and CAD data.
- Research future trends of Smart Home systems and predict customer needs in the next 10 years and their impact on the building envelope.
- Develop sensor and control (embedded and otherwise) technologies and techniques for intelligent enclosure systems.
- Create active surface (inside) temperature control: MRT control which allows reduction of T-stat setting in winter, resulting in potentially lower energy use winter and summer while increasing comfort.

#### *Rain Screen*

- Develop, refine, and promote rain screen technology for residential wall assemblies.

#### *Roof/Attic Systems<sup>22</sup>*

- Promote R&D to minimize arbitrary decisions in roof maintenance and repairs. The following areas are suggested:
  - When to leave a roof in place and “reuse” the insulation
  - Studies and dissemination on roof drying
  - Tools that tell when to re-roof and when to re-cover shingles
  - Life performance of recycled versus new roofing materials
  - Increased use of design tools for wet/problem areas
- Research capability problems with ice dams and moisture.
- Research potential benefits of roof insulation and conditioned attics versus ceiling insulation.

- Develop advanced roofing materials that can increase heat rejection (avoid heat islands) and environmental efficiency (run-off from asphalt shingles; green buildings).
- Increase workers' protection through the development of new materials and/or new systems; e.g. systems that reduce worker exposure to particulate and gaseous materials; materials that are less toxic/irritating.
- Intensify research of living roofs and their potential benefits.

#### *Super Walls*

- Create various kinetic wall assemblies to increase the integration between interior and exterior spaces.
- Develop wall systems that are low energy losers but, more important, are impervious to moisture, water, air infiltration, and insects, and can withstand natural disasters. The design should be adaptable to different climates.

### **PROCESS/DESIGN**

#### *Advanced Framing*

- Promote engineered framing technology (reduces amount of materials) in residential construction.
- Develop and demonstrate durable and thermally efficient building materials and more efficient framing techniques.
- Design low-cost connections between steel-framed interior walls, roof trusses, and floor joists.
- Research opportunities to modify existing wood structural building envelope materials to increase their thermal barrier properties.

#### *Automation*

- Develop control systems and robotic mechanisms for the viable implementation of on-site automated material handling, sorting, assembly, and finishing of entire building systems. Possible scenarios would be the development of various mechanical and computational systems for the on-site automated assembly of exterior walls, foundation systems, roof assemblies, and other fully functional building assemblies.

#### *Daylight and Passive Solar Design*

- Develop glare reduction devices that optimize daylighting savings potential. Glare-reduction devices located outside glazing line would reduce the need for occupants to close blinds and turn on lights, and would maintain desirable solar gain during heating seasons. The characteristics of such devices could be linked to exterior conditions through a control system.
- Improve daylighting control systems (e.g. louver systems that replace interior lighting).
- Promote the design of passive solar heating and cooling load avoidance, including building orientation and shading.
- Promote the design of buildings with roof orientations suitable for solar water heating and photovoltaics, and install plumbing chases for future solar system installation.

<sup>22</sup>Current work on roof drying at ORNL, SPRI, and RCI; a study is under way by DLR consultants on residential re-roof decision making.

- Develop daylighting system that has almost no heat gain and distributes light evenly. Measure effect on occupants.
- Conduct productivity research associated with daylighting.

#### *Design for Adaptability*

- Develop design concepts for building envelopes (separate for low-, medium-, and high-rise) that will facilitate future changes from one building type to another.
- Develop new "open architecture" knowledge of product integration principles that can reduce dependencies for ease of assembly, disassembly, replacement, and repair.
- Develop "plug-n-play" components and systems that can be easily added and removed.
- Design foundations that allow for movable walls.
- Design basements that are "potentially furnishable."

#### *Design for Intelligence*

- Develop a design process for intelligent materials and systems.

#### *Design Tools*

- Develop tools that allow design professionals to perform integral analysis and design of buildings. These tools should be coupled with a drafting package for additional convenience.
- Develop CAD-based expert systems combining graphical and script-based capabilities to describe typical interfaces in building envelopes to:

Give up-to-date information on available products in a product database

Provide direct feedback about the problems that need to be solved in product interfaces

Give feedback on assembly performance with a given product specification

Support visualization of the composition and joints between products

Have parametric behavior of elements

- Analyze the economic and technical advantages of higher-value-added "for-stock" components in terms of life-cycle costs of building envelopes made from such products versus conventional products.

- Continue to develop a database of life-cycle costs for residential construction.

#### *Modular Coordination*

- Develop underlying modular dimensioning strategies for enclosure systems that minimize waste during both manufacturing and construction and represent a high degree of dimensional compatibility with other building components.

#### *Natural Ventilation/IAQ*

- Develop design methods and/or materials that allow for natural, nonmechanical air movement through the building envelope.

#### *Recycling/Reuse Processes*

- Create market incentives/information support structure for the recycling/reuse infrastructure of construction materials, equivalent to U.S. cardboard recycling or German wood pallet recycling. Incentives could include policy, government procurement, and/or market development
- Develop fabrication and glazing technologies for insulated glass units, allowing renewal by disassembly and resealing when edge seals fail, so that durable materials remain in service.

#### *Regional Design*

- Research proper processes that customize the design of building envelopes to allow for regional climatic differences.

### PERFORMANCE EVALUATION

#### *Modeling/Testing*

##### *Energy*

- Create a database and design tool for roof designers that tie all "energy effects" of roof products and assembled roof. Some performance testing will be needed to fill data gaps (how color, mass, and insulation affect each other).
- Develop a building modeling program that adequately predicts energy losses through roofs so roof systems can be compared, as well as through basements and foundations so those systems can be compared.

#### *Monitoring/Testing*

- Use existing organizations that have testing protocols for developing testing systems, new protocols, and national standards. Industry leaders need to be involved in pushing for industry standard testing in industry group meetings and as a competitive advantage in the marketplace. This will drive all competitors to standards.
- Develop diagnostic tools to measure and evaluate proper installation of various envelope components.

##### *Disaster Resistance*

- Create wind and hail standards and design guides for roofs. In addition, data for a variety of roof types (steep and flat) at various speeds and pressures is needed.
- Develop a test missile that simulates hail and can be effectively used on both soft and brittle materials.
- Design a test that evaluates all discontinuous products for steep roofs and one that evaluates dynamic performance of flat roofs.
- Determine response of panelized walls to earthquake forces.
- Create detection and monitoring technologies to evaluate critical loads due to tornadoes, earthquakes, and other catastrophic events.

#### *Durability*

- Develop durability predictor curves based on a material's chemical, galvanic interaction with temperature, humidity, and structural performance (e.g., brick durability).
- Develop tests on the longevity<sup>23</sup> of roofing and other building materials. These tests should include the effects of:
  - Stress from cyclical temperature changes
  - Reflectivity
  - Temperature of ventilated/unventilated attics and decks
  - Ultraviolet, rain, and wind exposure
  - New inorganic materials
- Develop criteria for siding materials to define the level of durability of these products.

- Increase knowledge of stucco properties, determine how properties affect applications, and integrate findings into a comprehensive stucco best practices guide.

#### *Moisture*

- Formulate and validate testing of compliant roof/wall assemblies to detect moisture migration and water penetration under static loading.
- Create tools to predict condensation of moisture within building envelopes and standard details to reduce condensation in building envelope.
- Develop industrial protocol and equipment for monitoring moisture in building envelopes during and after construction.
- Develop material data for use in moisture analysis.

#### *Rating Criteria*

- Develop research criteria to improve acceptance rate for new building products and materials, so innovations are evaluated based on the merits of the new technology and not only on comparison with existing technologies.
- Develop equitable procedures to measure in-place performance of building materials. These procedures would take into account R-value, air presence, durability, energy use, health, etc.
- Combine all existing energy-rating agencies into a single body that measures building performance for a period of several years after construction.
- Develop means (such as an "energy tag") to communicate the life-cycle or annual energy cost of a building.
- Create a catalog and database containing information on the IAQ performance of sealants, adhesives, and finishes.

<sup>23</sup>NIST has the capability to independently or collectively vary the effect of temperature, humidity, UV (intensity and wavelength), and mechanical load on samples and determine the importance of these effects in aging performance.

## NEXT STEPS

This roadmap is a living document, reflecting the beginning of a multi-year process. It outlines an ambitious vision for the building envelope industry and breaks into manageable pieces the work that needs to be done. It serves as a resource for both the public and private sectors and offers a framework for greater collaboration across the industry. The roadmap also provides guidance for government agencies in planning future activities, particularly in forming R&D partnerships with industry.

The technology roadmap intentionally excludes detailed implementation approaches. These will be jointly developed between government and industry as the roadmap strategies are analyzed and enriched. One early implementation step will be to investigate existing efforts and other roadmaps already under way and determine how they might be leveraged to further the building envelope vision and avoid duplicate effort.

Federal collaborative programs and the building envelope industry must continue working together to overcome the five market/policy barriers and leverage efforts for the technology strategy. Each action will require different champions and levels of collaboration and involvement. Many of the “high-impact” and “high-priority” technical activities require a great deal of cooperation,

and therefore warrant a significant government facilitation/contribution role. DOE will use this roadmap to identify areas that coincide with national interests and public policy and align its Federal RD&D agenda accordingly. Other Federal programs (including PATH) have also expressed commitments toward implementation of this roadmap.

### FUTURE COLLABORATION

How will industry continue to work together and with DOE to contribute toward the implementation of the *Building Envelope Technology Roadmap 2020*? Suggested next steps include:

- A half-day industry-government working session to kickstart the implementation phase after the rollout.
- Formation of an industry task group to address appropriate industry and government roles in implementing the roadmap.
- Establishment of ad-hoc working groups to examine the barriers and research areas in greater depth and to develop detailed plans for each.
- Continued “course correction” meetings with industry and government to keep the roadmap document alive and evolving, in line with new realities, opportunities, and achievements.

Feedback on the technology roadmap is welcome. In particular, DOE and other sponsoring organizations welcome input on which of the identified activities most directly relate to your organization’s goals and needs and whether your organization would want to be an active participant in implementing these activities. To become involved, contact one of the co-sponsoring organizations or the U.S. Department of Energy.

## ACKNOWLEDGEMENTS

### A NOTE FROM . . .

Ronald Santoro, Team Leader  
*Building Envelope Technology  
Roadmap 2020*

As team leader of the roadmap development process for DOE's Office of Building Technology, State and Community Programs (BTS), I wish to thank the hundreds of organizations and individuals that contributed to this significant effort:

AFL-CIO Building and Construction Trades Department  
American Architectural Manufacturers Association (AAMA)  
American Forest & Paper Association (AFPA)  
American Portland Cement Alliance (APCA)  
American Solar  
Andersen Corporation  
Aspen Research  
Ball State University  
BP Solarex  
Brick Industry Association  
British Columbia Building Envelope Research Consortium (BC-BERC)  
Building Technology  
Building Technology Group, Department of Architecture, Massachusetts Institute of Technology  
Cellulose Insulation Manufacturers Association (CIMA)  
Celotex  
Center to Protect Workers Rights (AFL-CIO)  
CertainTeed Corporation  
Champion Enterprises, Inc.  
Commonwealth of Massachusetts Division of Energy Resources  
Corbond Corporation  
Construction Technology Laboratories, Inc. (CTL)  
DAP, Inc.

Department of Business, Economic Development, and Tourism (DBEDT), State of Hawaii  
Development Center for Appropriate Technology  
David L. Roodvoets Consulting (DLR) (representing the National Roofing Contractors Association)  
DMO Associates  
The Dow Chemical Company  
DuPont Tyvek Weatherization Systems Energy Services Group  
The Engineered Wood Association (APA)  
Engineering Field Activity Chesapeake, Naval Facilities (EFACHES, NAVFAC)  
Exterior Insulation Manufacturers Association (EIMA)  
Florida Solar Energy Center (FSEC)  
General Electric Company  
Grace Construction Products  
Habitat for Humanity  
Icynene, Inc.  
Innovative Design  
Institute for Research in Construction (IRC)  
Intech Consulting, Inc.  
Jeld-Wen, Inc.  
Johns Manville  
Louisiana Pacific  
Manufactured Housing Institute  
Marvin Windows  
Masco Corp.  
National Association of Home Builders (NAHB)  
National Association of Home Builders Research Center (NAHBRC)  
National Concrete and Masonry Association (NCMA)  
National Institute of Building Sciences, Building Environment Thermal Energy Council (NIBS, BETEC)  
National Institute of Standards and Technology (NIST)  
New York State Energy Research and Development Authority (NYSERDA)  
North American Insulation Manufacturers Association (NAIMA)  
Ohio Office of Energy Efficiency  
Owens Corning

Partnership for Advancing Technology in Housing (PATH)  
Pennsylvania Housing Research Center  
Portland Cement Association (PCA)  
Rock Wool Manufacturing  
Rutgers Cooperative Extension  
Seattle Department of Design Construction and Land Use  
South Carolina Institute for Energy Studies  
Spray Polyurethane Foam Alliance—America Plastics Council (SPFA-APC)  
State Service Organization (SSO)  
Superior Walls of America, LTD  
Sustainable Building Industry Council (SBIC)  
Texas A&M  
Trex Company  
U.S. Department of Energy (DOE)  
U.S. Department of Housing and Urban Development (HUD)  
United States Gypsum Corporation (USG)  
University of Minnesota, College of Architecture & Landscape  
University of Waterloo  
Virginia Tech  
Washington State University  
Weatherization Assistance Program—Technical Assistance Center  
What's Working (representing the U.S. Green Building Council)  
Window and Door Manufacturers Association (WDMA)

Special thanks to **Ed Barbour** and **Kathryn Fry**, of Arthur D. Little, for their role in organizing and documenting the roadmap process and creating the first roadmap drafts; **Doug Brookman**, of Public Solutions, for his creative facilitation of the three workshops; and the team at **Brandeggee** for their vision and creativity in bringing the roadmap together into the document you see today.

## ABBREVIATIONS & ACRONYMS

ACTE <i>Association for Career and Technical Education</i>	DOE <i>U.S. Department of Energy</i>	NTRMA <i>National Tile Roofing Manufacturers Association</i>
ADL <i>Arthur D. Little, Inc.</i>	ECCO <i>Environmental Conference of Concrete Organizations</i>	ORNL <i>Oak Ridge National Laboratory</i>
APA <i>The Engineered Wood Association</i>	EPA <i>Environmental Protection Agency</i>	PATH <i>Partnership for Advancing Technologies in Housing</i>
ARMA <i>Asphalt Roofing Manufacturers Association</i>	HUD <i>U.S. Department of Housing and Urban Development</i>	PPM <i>parts per million</i>
ASHRAE <i>American Society of Heating, Refrigeration, and Air Conditioning Engineers</i>	HVAC&R <i>Heating, Air Conditioning and Refrigeration</i>	PRS <i>Performance Rating System</i>
ASTM <i>American Standards for Testing and Materials</i>	IAASI <i>International Applied Arts and Science Institute</i>	PV <i>photovoltaic</i>
BEES <i>Building for Environmental and Economic Stability</i>	IAQ <i>indoor air quality</i>	R&D <i>research and development</i>
BERC <i>Building Envelope Research Consortium</i>	IBHS <i>Institute for Business &amp; Home Safety</i>	RCI <i>Roof Consultants Institute</i>
BETEC <i>Building Environment Thermal Envelope Council</i>	ICBO <i>International Conference of Building Officials</i>	RD&D <i>research, development, and deployment</i>
BETR <i>Building Envelope Technology Roadmap</i>	ICC <i>International Code Council</i>	R-value <i>measure of thermal resistance</i>
BOCA <i>Building Officials and Code Administrators International, Inc.</i>	ISO <i>International Standards Organization</i>	SBCCI <i>Southern Building Code Congress International, Inc.</i>
BPG <i>Best Practices Guide</i>	LEEDS <i>Leadership in Energy and Environmental Design (U.S. Green Building Council Rating System)</i>	SBIC <i>Sustainable Building Industry Council</i>
BTS <i>Office of Building Technology, State and Community Programs</i>	MMEWS <i>Consortium for Moisture Management for Exterior Wall Systems</i>	SkillsUSA-VICA <i>The Vocational Industrial Clubs of America, Inc.</i>
Btu <i>British thermal unit</i>	MRT <i>mean radiant temperature</i>	SPRI <i>Sheet Membrane and Component Suppliers to the Commercial Roofing Industry</i>
CAD <i>computer-aided design</i>	NAHB <i>National Association of Home Builders</i>	USGBC <i>U.S. Green Building Council</i>
CIB <i>International Council for Building</i>	NASDVTEC <i>National Association of VoTech Directors</i>	UV <i>ultraviolet</i>
CMHC <i>Canada Mortgage and Housing Corporation</i>	NCMA <i>National Concrete and Masonry Association</i>	VOC <i>volatile organic compound</i>
CMU <i>concrete masonry unit</i>	NES <i>National Evaluation Service</i>	WDMA <i>Window &amp; Door Manufacturers Association</i>
CUREe <i>California Universities for Research in Earthquake Engineering</i>	NIST <i>National Institute of Standards and Technology</i>	
DLR <i>David L. Roodvoets Consulting</i>	NRCA <i>National Roofing Contractors Association</i>	



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**Or visit the Building Envelope Roadmap website at:  
[www.eren.doe.gov/buildings/technology\\_roadmaps/envelope](http://www.eren.doe.gov/buildings/technology_roadmaps/envelope)**